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Electrically Controlled Frequency Reconfigurable Comb Type Antenna for Wireless Communication

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Abstract— **Electrically controlled frequency reconfigurable comb type antenna is presented in this paper. Reconfigurability is achieved by placing a PIN diode in each slot of the comb type antenna. The proposed antenna has very compact size and works on 8 different bands depending upon the state and number of PIN diode (ON/OFF). Ansoft Designer 7 is used to simulate the equivalent model for the PIN diode and proposed antenna is fabricated on FR4 substrate using photolithography process. As the antenna reconfigure its resonating frequency from 1st band to 8th band, directivity increases from 3.28 to 4.02 and radiation efficiency increases from 75.3% to 93.45% due to the improvement in impedance matching at higher band.**

Index Terms— **PIN diode, frequency reconfigurable, Micro strip patch antenna, comb type antenna, multi band wireless communication.**

I. Introduction

In modern times, wireless devices are not limited to one standard as they can operate at multiple frequencies. Multi-mode terminals have received great attention and popularity because one can access multiple applications such as GPS, GSM, WLAN, Bluetooth etc. in a single device[1-2]**.** So there is an immense need of smart system, which can satisfy above demands. Reconfigurable antenna is the key solution and is a promising paradigm as it can modify its characteristics in real time within a single structure[1-2]. The reconfigurable characteristics of antennas are very valuable for many modern wireless communication applications because they can efficiently utilize spectrum and power for highly secure multimode data transmission [1-6].

Frequency reconfigurable antennas are single antenna that can dynamically transmit or receive multiple frequency bands and patterns [2-6]. Such system has ability to monitor the gaps (white spaces/unused frequency) continuously in finite frequency spectrum occupied by other wireless systems. These antennas can dynamically alter their transmit/receive characteristics to operate within desired frequency bands, thereby minimizing interference with other wireless systems and maximizing the throughput. Frequency reconfigurable antennas have advantages over conventional antennas, such as reducing the number of antennas thus reducing the mutual interferences, complexity and cost of the system[1-2]. Generally reconfigurability can be obtained using many techniques such as tunable elements in the feeding networks, adaptive matching networks, tunable filters and tunable phase shifters[14]. Switches can been implemented using RF-MEMS [7-10], PIN diodes [1,11,15] and varactors [12-13]etc.

In this paper, a very compact electrically controlled frequency reconfigurable comb type antenna is presented. Eight pairs of PIN diode is used to achieve reconfigurability of microstrip patch antenna. The proposed antenna works on 8 different bands depending upon the state and number of PIN diode (ON/OFF). There is improvement in radiation efficiency of the antenna from 75.3% to 93.45% and directivity 3.28 to 4.02 as antenna reconfigure its resonating frequency from 1st band to 8th band with the help of PIN diodes.

II. Theory

Due to many significant advantages like lightweight, low profile, simple and inexpensive to manufacture using modern printed-circuit technology; microstrip antenna is the best choice for modern wireless and mobile applications [16-17]. A rectangular microstrip patch antenna of length *L*, width *W* resting on a substrate of height *h* is shown in Fig. 1. The CAD formulae for the dimension (*L, W)* calculation for patch [16-17] at resonating frequency f_0 on a substrate with dielectric constant ε_r and height *h* are:

Effective dielectric constant

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{\frac{-1}{2}} \quad (1)$$

$$\text{Patch width: } W = \frac{c}{2f_0\sqrt{\frac{\varepsilon_r+1}{2}}} \quad (2)$$

$$\text{Patch length: } L = \frac{c}{2f_0\sqrt{\varepsilon_{re}}} \quad (3)$$

Extended length of patch due to fringing field

$$\Delta L = 0.412h\frac{(\varepsilon_{re}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{re}-0.258)\left(\frac{W}{h}+0.8\right)} \quad (4)$$

Effective patch length: $L_{eff} = L + 2\Delta L$ (5)

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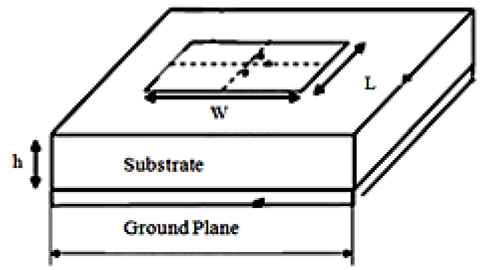

Fig. 1: Basic Rectangular Patch antenna

The total input impedance is given by eq. (6)

$$Z_{in} = \frac{1}{2(G \pm G_{12})} \tag{6}$$

where G is conductance and given by eq.(7)

$$G = \begin{cases} 1/90(W/\lambda)^2 & W \ll \lambda \\ 1/120(W/\lambda) & W \gg \lambda \end{cases} \tag{7}$$

Where W = patch width and λ= resonant wavelength. If G_{12} is the mutual conductance between two slots, J_o is Bessel function of first kind than

$$G_{12} = \int_0^{\pi} \left[\frac{\sin\{\frac{k_0 W \cos\theta}{2}\}}{120\pi^2 \cos\theta} \right]^2 J_0\,(k_0 L \sin\,\theta) \sin^3\theta d\theta \tag{8}$$

The above formulae are used to design a rectangular microstrip patch antenna.

III. Design Approch

The geometry of the proposed frequency reconfigurable comb type antenna for wireless is depicted in Fig 2. This antenna was printed on FR4 substrate with the dielectric constant of 4.4 and the substrate thickness of 1.57 mm. In this work, inset microstrip feeding technique is used.

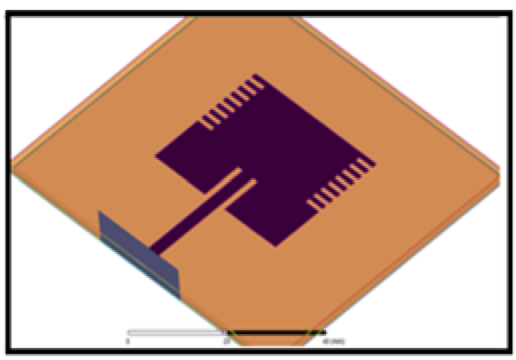

Fig 2: Frequency Reconfigurable Comb type antenna

In order to get better performance like efficiency, gain, and directivity etc. antenna should be properly matched with feed line. The location of inset cut point is adjusted to match with its input impedance (usually 50 ohm). The optimized parameters of proposed antenna are: length=28.2 mm, width=36.48 mm on a ground plane of size 60x60mm^2. Antenna is fed by microstrip transmission line with a metal strip of width 3mm and length 30mm. The eight slot on the top patch metallization are 1mm wide and 4mm long. Eight PIN diode pairs (a-aa, b-bb.......h-hh etc.) are introduced in between the 8 pair of teeth along the length of patch antenna as shown in Fig 3. According to the state of PIN diode; corresponding teeth of the comb type antenna connect/disconnect from the main patch, hence electrical length of the antenna can be varied so that resonating frequency can be reconfigured.

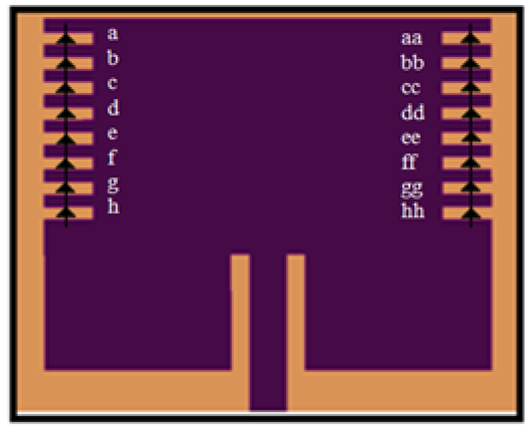

Fig 3: Electrically controlled Frequency reconfigurable comb type antenna with PIN diode

The proposed antenna works on 8 different bands depending upon the state and number of PIN diode. The ON and OFF conditions of switches are realized by forward and reverse biasing of PIN diodes. Ansoft HFSS 14 and Ansoft Designer7 are used to simulate and model the proposed antenna.

IV. Modelling Of Pin Diode

The ON and OFF conditions of switches are realized by forward and reverse biasing of PIN diode. Ideally, when a forward bias is applied to make the PIN diode ON, the switch

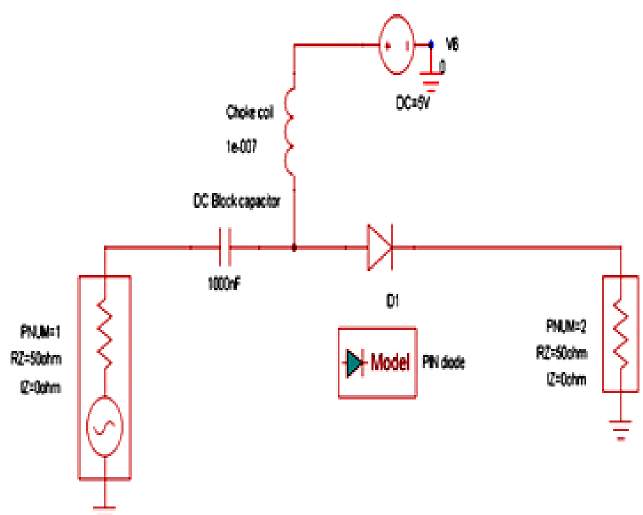

Fig 4: PIN diode circuit connection for diode modelling

would offer low impedance and acts as short circuit. On the other hand, when a reverse bias is applied to make the PIN diode OFF, it exhibits high impedance and acts as open circuit. Working of PIN diode can be easily explained by Fig. 4 which

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consists of a DC block capacitor (1µF) and a RF choke coil (0.1µH). If diode is forward biased it can be modeled as a resistor of 1 ohm and if diode is in reverse biased it can be modeled as a parallel combination of 0.1µF capacitor and 25 K ohm resistor. When PIN diode is ON; insertion loss is 0.1 dB and return loss is below -15dB from 1GHz to 10 GHz as shown in Fig. 5. When PIN diode is OFF; return loss is 0.07 dB and insertion loss is below -15dB which shows no propagation of power from source to load terminal from 1GHz to 10 GHz as shown in Fig. 6.

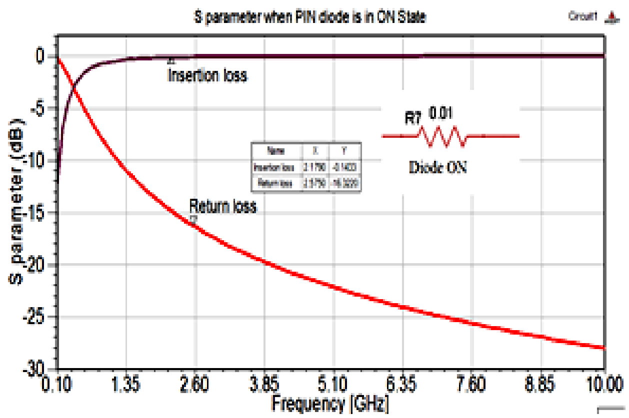

Fig 5: S parameter vs. frequency when PIN diode is Forward biased

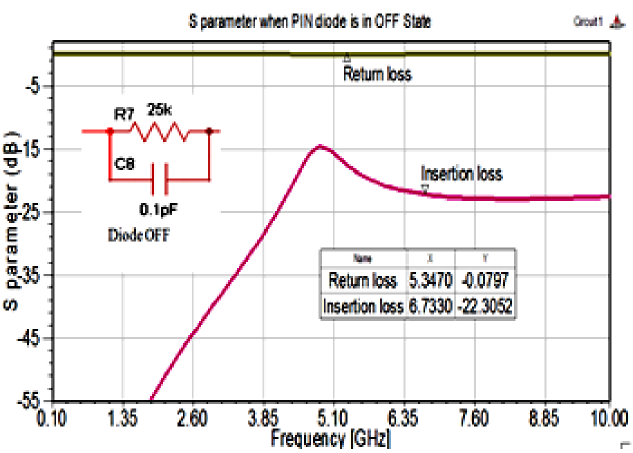

Fig 6: S parameter vs. frequency when PIN diode is Reverse biased

V. Results And Discussion

Fig. 7 shows the simulated results for return loss of Comb Type Reconfigurable microstrip patch antenna. The overall goal of as designed antenna design is to achieve return loss below -10dB for good performance.

When no diode is switch ON antenna have first resonance in a frequency range of 2.2 GHz. As diode a-aa is forward biased there is conducting path between 1st teeth of comb with the main patch hence electrical length of the comb antenna decreases and it will resonates at higher frequency i.e. 2.23 GHz. As the diode b-bb is forward biased than 2nd teeth of the comb antenna merges with the main patch and antenna will resonates at higher frequency 2.26 GHz due to decreases in electrical length.

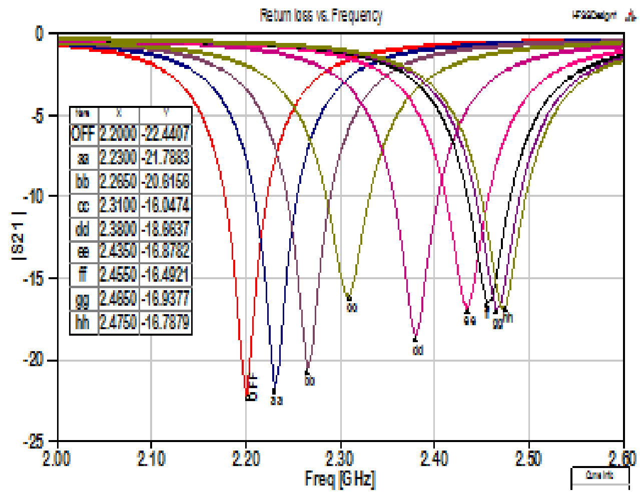

Fig 7: Return loss S_{11} (dB) vs. frequency for all switch condition

Table I: Simulated value of antenna parameters under different switch condition

S.No	Switch Condition	Freq. GHz	S11 dB	Rad. Eff %
1.	All OFF	2.2	-22.44	75.3
2.	a-aa (ON)	2.3	-21.78	75.6
3.	b-bb (ON)	2.26	-20.61	69.25
4.	c-cc (ON)	2.31	-16.0474	77.37
5.	d-dd (ON)	2.38	-18.6637	89.25
6.	e-ee (ON)	2.435	-16.87	90.75
7.	f-ff (ON)	2.455	-16.49	91.912
8.	g-gg (ON)	2.465	-16.93	92.82
9.	h-hh (ON)	2.475	-16.78	93.45

Fig. 8 shows the Radiation efficiency vs. angle for all switch condition. Table 1 shows that return loss at different resonating frequency under all switch condition is below -10dB.Results conclude that radiation efficiency of comb type antenna increase from 75.3% to 93.45%.

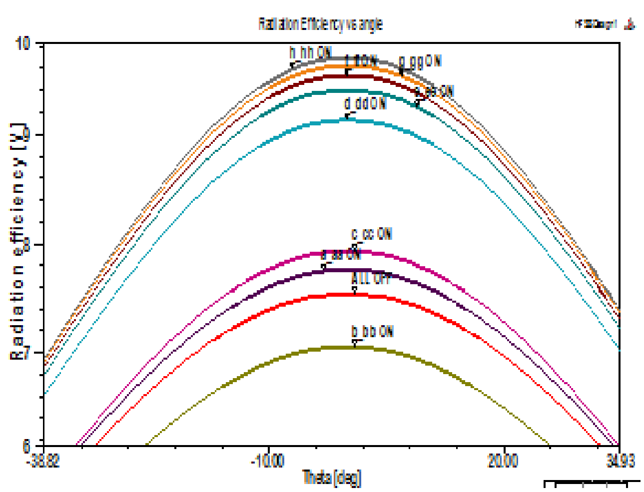

Fig 8: Rectangular plot for Radiation efficiency vs. theta for all switch condition

So by modifying the geometry with the help of PIN diode the resonating frequency of the patch antenna can be reconfigure in a bandwidth of 275 MHz. The radiation pattern of comb type antenna under all switch condition is shown in Fig. 9. Results conclude that efficiency of antenna under

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all condition is greater than 70%. The simulated value for gain and directivity of the patch antenna under different switch condition is shown in Table 2.

TABLE II: SIMULATED VALUE OF ANTENNA PARAMETERS UNDER ALL SWITCH CONDITION

S.No	Switch Condition	Freq GHz	Gain (dBm)	Directivity
1.	All OFF	2.2	31.49	3.28
2.	a-aa (ON)	2.3	31.68	3.34
3.	b-bb (ON)	2.26	34.55	3.31
4.	c-cc (ON)	2.31	32.18	3.5
5.	d-dd (ON)	2.38	33.268	3.878
6.	e-ee (ON)	2.435	33.285	3.95
7.	f-ff (ON)	2.455	33.3249	3.98
8.	g-gg (ON)	2.465	33.33	4
9.	h-hh (ON)	2.475	33.882	4.02

Directivity vs. angle under all diode condition is shown by Fig. 10 which clearly indicate that directivity of the antenna increases from 3.28 to 4.02.

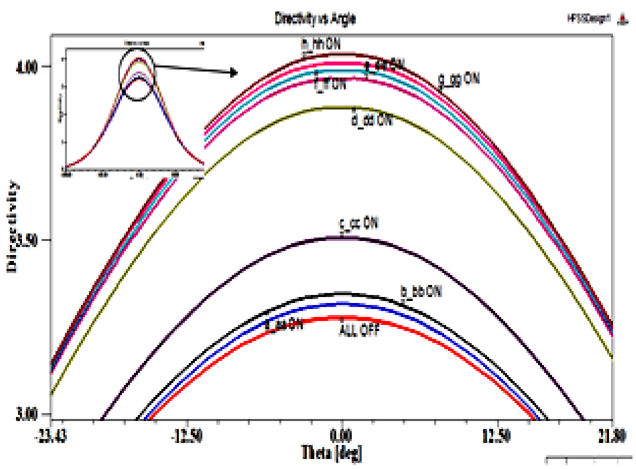

Fig 10: Rectangular plot for directivity vs. theta for all switch condition

Gain vs. angle under all diode condition is shown by Fig. 11 which clearly indicate that Gain of the antenna in all cases is above 1 dB. Fig. 11 shows the polar plot for gain vs. theta. Fabrication of comb antenna is done by photolithography process. A uniform layer of S1818 photo resist is deposited on substrate using spin coater. the mask for fabrication of antenna transferred on the FR4 substrate by exposing the substrate using *i* line UV Lamp. Pattern is formed by etching the developed substrate using $FeCl_3$ as shown in Fig. 12. A sequential method for the fabrication using photolithography technique is tabulated below in Table 3.

VI. CONCLUSION

Frequency Reconfigurable Comb type Microstrip Patch antenna is successfully simulated in Ansoft HFSS 14. Ansoft Designer 7 is used to simulate the equivalent model for the PIN diode and proposed antenna is fabricated on FR4 substrate using photolithography process. From the simulated results it can be easily seen that antenna reconfigure its resonating frequency in a range of 2.2 GHz to 2.475 GHz. The

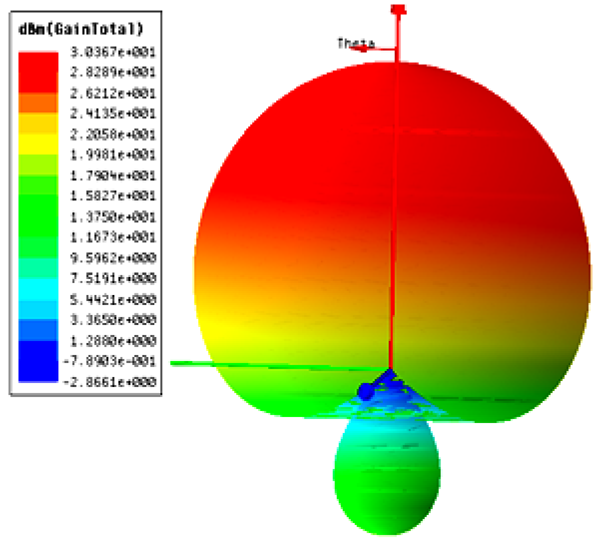

Fig 11: Polar plot for Gain vs. theta

TABLE III: PHOTOLITHOGRAPHY TECHNIQUE

Step no:	Description	Equipment	Conditions
1	Substrate cutting	Cutter	Prevent corners from damaged
2	Substrate cleaning	Using DI water + Acetone+ Trichloroethylene	1 min,1 min 80^0C for 20 min
3	Coating of photo resist S1818	Spin coater (Apex instruments)	3000 rpm for 30 sec
4	Pre Bake	Oven	100^0 C for 25 min, 115^0 C for 60 sec
5	Exposure	100 W *i* line UV Lamp	2.30 min
6	Develop	Using 10% NaOH	40 sec
7	Rinse in DI water	Elix Millipore Lab water Purifier	1 min
8	Dry	Electronic dryer	Blow and dry both side on top
9	Hard Bake (Post Bake)	Oven Hot Plate	120^0 C for 30 min 120^0 C for 5 min
10	Etching	30% of $FeCl_3$	20 min

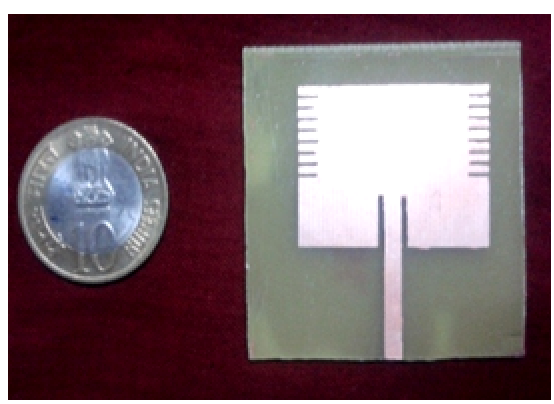

Fig 12: Fabricated Frequency Reconfigurable Microstrip patch antenna

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proposed antenna has very compact size. There is improvement in radiation efficiency of the antenna from 75.3% to 93.45% and directivity 3.28 to 4.02 as antenna reconfigure its resonating from 1st band to 8th band. Gain of the antenna in all cases is greater than 1dB.

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